Evaluation of Diesel Particulate Filter Systems at INCO Stobie Mine - Filtration Efficiency Tests Conducted in May 2002

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Introduction

- **Evaluation of Diesel Particulate Filter Systems at INCO Stobie Mine**
  - The project has for objective long term evaluation of diesel particulate matter filtration systems retrofitted to heavy- and light-duty diesel powered vehicles at the mine.
  - Testing conducted at INCO in May 2002 was one in the series of the testing performed periodically with objective to determine filtration efficiencies of the evaluated filtration systems.
  - The project is sponsored by Diesel Emissions Evaluation Program (DEEP).

Vehicles/Engines/Filtration systems

Vehicle number	#820	#445	#362	#2180	#621
Vehicle type	Wagner STB8	Wagner STB8	Wagner STB8	Kubota M5400	Kubota M5400
Engine make and model	Deutz F12L413FW	DDEC Series 60	DDEC Series 60	Kubota F2803B	Kubota F2803B
Engine displacement, [liters]	19.1	11.1	11.1	2.7	2.7
Engine rated output, [kW/hp]	207/277	242/325	213/285	40.3/50	40.3/50
Torque Converter Stall, [rpm]	2270	1990	2130	N/A	N/A
Engine Speed at High Idle, [rpm]	2480	2180	2190	2910	2610
Engine Speed at Low Idle, [rpm]	720	600	600	970	960
Filter Brand	Johnson Matthey	ECS- Unikat	Engelhard	ECS - Unikat	DCL
Filter Model	DPF 201	Combifiter S	DPX 2	Combifilter S	Mine-X
Filter Media	SiC	SiC	Cordierite	SiC	SiC
Filter Hours Prior to Test	410	74	1855	10	75
Regeneration concept	passive + active	active	passive	active	active
Type of catalyst	fuel born, cerium	N/A	wash coat, platinum based	N/A	N/A
Type of active regeneration	on-board electrical	on-board electrical	N/A	on-board electrical	off-board electrical

Diesel Particulate Filter Systems – LHD #820

Johnson Matthey DPF installed on Deutz F12L413FW engine
Silicon carbide monolith, Passive+active regeneration: cerium-based fuel additive + on-board electrical regeneration

Diesel Particulate Filter Systems- LHD #445

ECS-Unikat DPF installed on DDEC Series 60 engine

Silicon carbide monolith

Active: on-board electrical regeneration

Diesel Particulate Filter Systems- LHD #362

Engelhard DPF installed on DDEC Series 60 engine

Cordierite monolith

Passive: light platinum coating

Diesel Particulate Filter Systems- Tractor 2180

ECS Unikat DPF installed on Kubota F2803B

Silicon carbide monolith

Active:on-board electrical regeneration

Diesel Particulate Filter Systems- Tractor #621

DCL DPF installed on Kubota F2803B

Silicon carbide monolith

Active:off-board electrical regeneration

Filter Efficiency Measurements Method

- Filter efficiencies were determined on a basis of the measurements made in the exhaust pipe upstream and downstream of the test filters.
- Tests were performed at surface shop at Stobie mine
- The emission from the LHDs were measured at steady state conditions including **torque converter stall, high idle, and low idle.**
- The emissions from the tractors were measured at **high idle and low idle conditions**.

Filter Efficiency Measurements Methods and Instrumentation

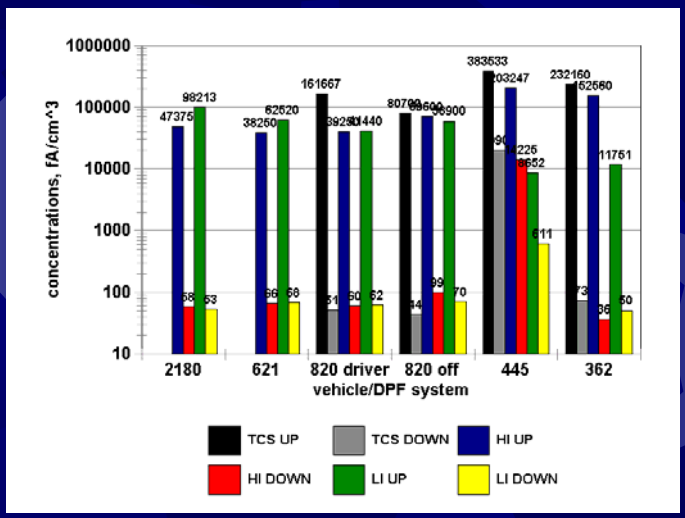
- Concentrations of polycyclic aromatic hydrocarbons/elemental carbon particles:
  - Photoacoustic Aerosol Sensor - PAS 2000;
  - Diluter MD19-2E.
- Concentrations and size distribution of particles by number:
  - Scanning Mobility Particle Sizer (SMPS);
  - Diluter MD19-2E.
- Exhaust opacity:
  - Two opacity meters - AVL DiSmoke 4000.

Instrumentation: Scanning Mobility Particle Sizer

The concentrations of PAHs/EC particles – PAS 2000 / MD19-2E measurements

- The concentrations of PAHs/EC particles in the exhaust of the LHDs were obtained for the following vehicle/engine operating conditions:
  - Torque converter stall (TCS)
  - High idle (HI), and
  - Low idle (LI).
- The same were obtained for the tractors operated at:
  - HI, and
  - LI.
- For each of the test conditions the results are presented as the concentrations averaged over three measurements performed upstream and downstream of the DPFs. The results were corrected for the dilution.

The concentrations of PAHs/EC particles (PAS 2000)



The concentrations of PAHs/EC particles (PAS 2000)

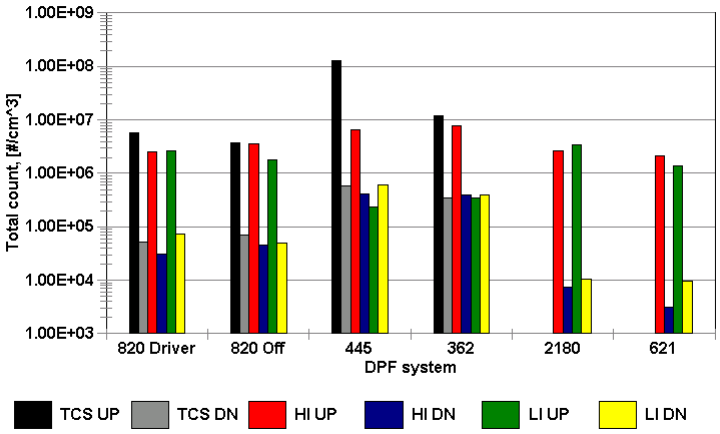
Vehicle	2180		621		820 driver			820 off			445			362		
Engine operating conditions	HI	LI	HI	LI	TCS	HI	LI	TCS	HI	LI	TCS	HI	LI	TCS	HI	LI
Efficiency, [%]	99.88	99.95	99.83	99.89	99.97	99.85	99.85	99.95	99.86	99.88	94.81	93.00	92.94	99.97	99.57	99.98

- The highest engine-out concentrations of PAHs/EC were observed for #445 and #362.
- The highest DPF-out concentrations of PAHs/EC were found in the exhaust of #445.
- The efficiency of ECS DPF on #445 in removal of PAHs/EC particles under 95%.
- The efficiencies of the other DPFs in removal of PAHs/EC particles were over 99.5%.

The number and size distribution of aerosols – SMPS / MD19-2E measurements

- The number and size distributions of aerosols in the exhaust of the LHDs were measured for the following vehicle/engine operating conditions:
  - Torque converter stall (TCS),
  - High idle (HI), and
  - Low idle (LI).
- The same were measured for the tractors operated at:
  - HI and
  - LI.
- The results were corrected for applied dilution.
- For each of the test conditions the total counts were averaged over three measurements performed upstream and downstream of the DPFs.

The number and size distribution of aerosols (SMPS)



The number and size distribution of aerosols (SMPS)

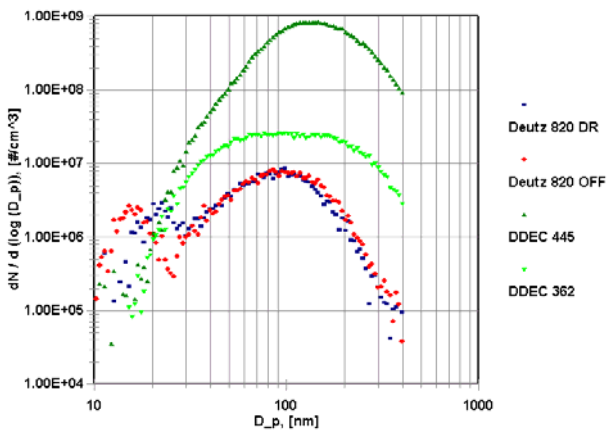
Vehicle	Torque converter stall			High idle			Low idle		
	Total count upstream	Total count downstr.	Filter Eff.	Total count upstream	Total count downstr.	Filter Eff.	Total count upstream	Total count downstr.	Filter Eff.
	#/cm^3	#/cm^3	%	#/cm^3	#/cm^3	%	#/cm^3	#/cm^3	%
2180				2.61E+06	7.28E+03	**99.72**	3.42E+06	1.04E+04	**99.70**
621				2.15E+06	3.17E+03	**99.85**	1.35E+06	9.62E+03	**99.29**
820 Driver	5.65E+06	5.23E+04	**99.07**	2.47E+06	3.09E+04	**98.75**	2.61E+06	7.34E+04	**97.19**
820 Off	3.67E+06	6.88E+04	**98.13**	3.47E+06	4.49E+04	**98.71**	1.76E+06	4.86E+04	**97.24**
445	1.30E+08	5.77E+05	**99.56**	6.49E+06	4.14E+05	**93.62**	2.34E+05	6.08E+05	**N/A**
362	1.18E+07	3.49E+05	**97.04**	7.89E+06	3.83E+05	**95.14**	3.50E+05	3.95E+05	**N/A**

- The largest engine-out concentrations were measured in the exhaust of #445 under TCS conditions.
- At TCS conditions the engine-out concentrations of #445 were one order of magnitude higher than corresponding concentrations observed for #362.

The number and size distribution of aerosols (SMPS)

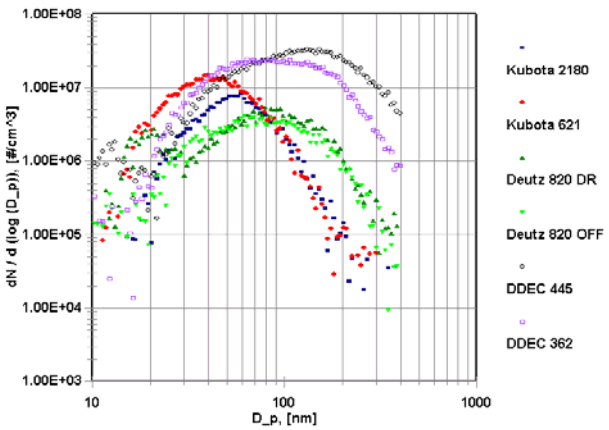
- At high idle conditions all three engines powering LHDs emitted equivalent number of particles.
- At high and low idle conditions the concentrations of particle in the raw exhausts of the tractors (#2180 and #621) were comparable to those measured in the raw exhaust of the LHDs (#820, #445, and #362).
- The highest concentrations of particles downstream of the filters were found in the exhaust of #445 (ECS) and #362 (Engelhard).
- The ECS filter on #445 exhibited the lowest efficiency (93.6% at HI) in reducing particle concentrations.

The number and size distribution of aerosols (SMPS) – Torque converter stall (LHDs)



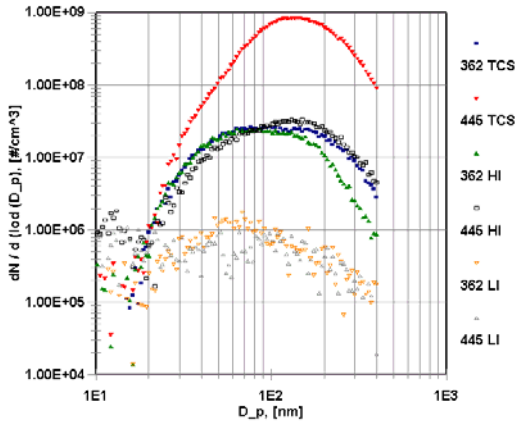
- #820 bimodal
  - cerium???
- #445 and #362 single modal.
- Engine out (11.1 liter DDEC Series 60) concentrations much higher for #445 (325 hp) than those for #362 (285 hp).

The number and size distribution of aerosols (SMPS) – High idle (all vehicles)



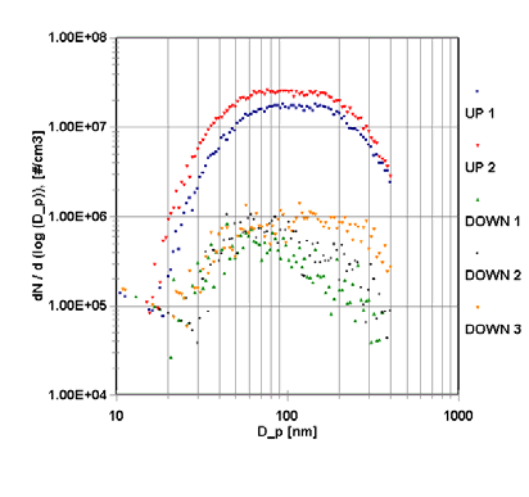
- #820 bimodal
  - cerium???
- #445, #362, #2180, and #621 single modal
- Engine out PM concentrations for #445 and #362 were comparable.
- Geometric means for tractors were much smaller than those for LHDs.

The number and size distribution of aerosols (SMPS) – Engine operating conditions (DDEC)



- Significant effects of engine operating conditions on size distributions and concentrations were evident for all tested vehicles.
- Very similar aerosol distributions were found in the exhaust of #362 at TCS (2130 rpm) and HI (2190 rpm) conditions.

The number and size distribution of aerosols (SMPS) - Performance of the filters



- The concentrations downstream of the filters were found to be couple orders of magnitude lower than those upstream of the filters.

The exhaust opacity AVL DiSmoke 4000

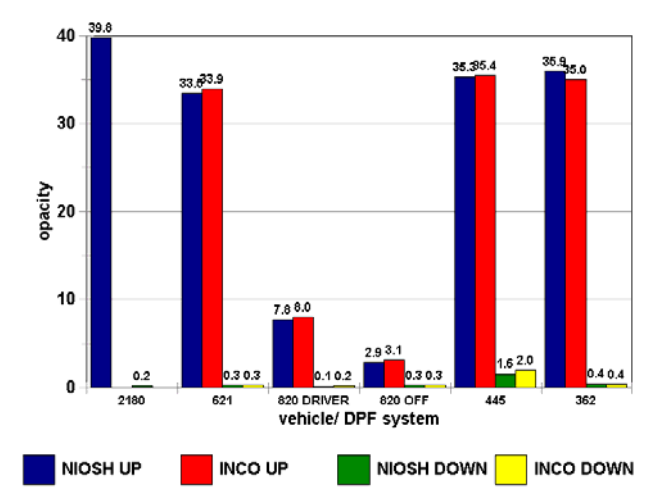
- The exhaust opacities of the LHDs were measured for the following vehicle/engine operating conditions:
  - Torque converter stall (TCS),
  - High idle (HI), and
  - Low idle (LI).
- The same were measured for the tractors operated at:
  - HI and
  - LI.
- For each of the test conditions the results were averaged over three measurements performed upstream and downstream of the DPFs.

The exhaust opacity

- The opacities upstream of the filters (except for #820) were in the range between 33.47 and 39.78.
- The opacities downstream of the filters (except for #445) were in the range between 0.13 and 0.43.
- The low efficiency of JMC filter on the off side of #820 is misleading.

Vehicle	Instrum.	Sampling location	Max. opacity, Average	Reduction %
2180	NIOSH	UP	39.78	99.41
	NIOSH	DOWN	0.23	
	INCO	UP		
	INCO	DOWN		
621	NIOSH	UP	33.47	99.20
	NIOSH	DOWN	0.27	
	INCO	UP	33.93	99.12
	INCO	DOWN	0.30	
820 driver	NIOSH	UP	7.77	98.28
	NIOSH	DOWN	0.13	
	INCO	UP	8.00	97.81
	INCO	DOWN	0.18	
820 off	NIOSH	UP	2.88	90.46
	NIOSH	DOWN	0.28	
	INCO	UP	3.13	90.43
	INCO	DOWN	0.30	
445	NIOSH	UP	35.27	95.56
	NIOSH	DOWN	1.57	
	INCO	UP	35.43	94.36
	INCO	DOWN	2.00	
362	NIOSH	UP	35.93	98.79
	NIOSH	DOWN	0.43	
	INCO	UP	35.00	98.86
	INCO	DOWN	0.40	

The exhaust opacity



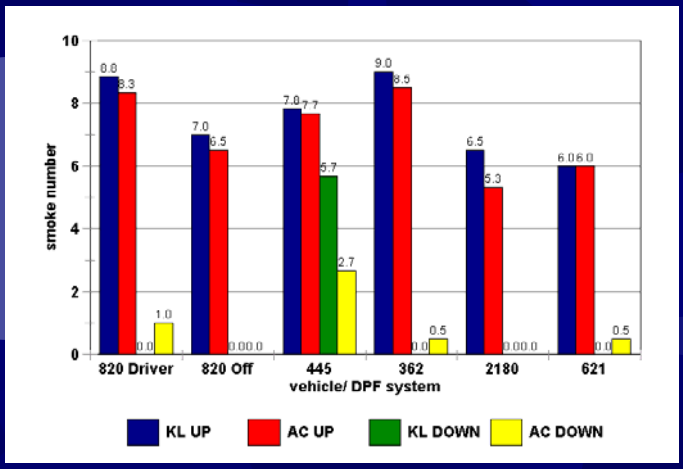
- The highest opacity at downstream side of the all tested filters was recorded for #445 retrofitted with ECS filter system.

Smoke number

Vehicle	Sampling location	Average smoke number	
		KL	AC
2180	UP	6.50	5.33
	DOWN	0.00	0.00
621	UP	6.00	6.00
	DOWN	0.00	0.50
820 driver	UP	8.83	8.33
	DOWN	0.00	1.00
820 off	UP	7.00	6.50
	DOWN	0.00	0.00
445	UP	7.83	7.67
	DOWN	5.67	2.67
362	UP	9.00	8.50
	DOWN	0.00	0.50

- The highest smoke numbers were observed for ECS DPF installed on #445.
- The method based on smoke number does not have resolution and accuracy of the other instruments used in this study but can be use as pass/fail test .

Smoke number

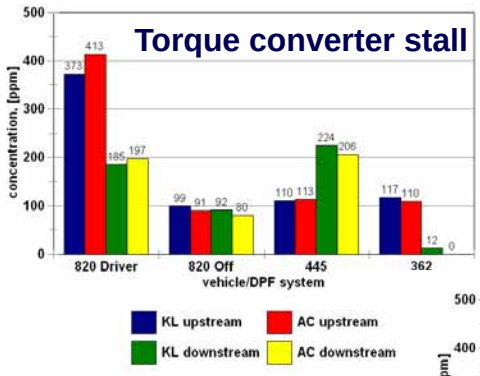


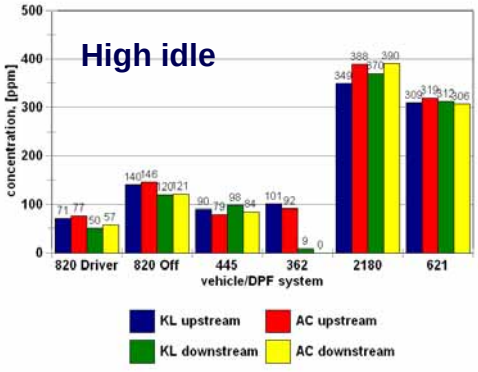
Gaseous emissions - Reductions

Vehicle	Instrum.	Torque converter stall CO reduction %	Torque converter stall NO reduction %	Torque converter stall NO2 reduction %	High Idle CO reduction %	High Idle NO reduction %	High Idle NO2 reduction %	Low idle CO reduction %	Low idle NO reduction %	Low idle NO2 reduction %
2180	KL				-5.9	4.7	10.5	2.3	-2.6	20.5
	AC				-0.5	11.7	22.4	3.3	1.2	22.0
621	KL				-0.9	8.4	7.4	3.9	12.7	9.4
	AC				4.0	12.0	11.0	2.7	13.6	4.7
820 driver	KL	50.4	-2.0	50.0	29.9	8.2	65.4	91.7	-1.4	79.2
	AC	52.2	2.7	68.2	26.1	12.2	76.5	84.4	-0.7	89.4
820 off	KL	7.4	-7.5	71.4	14.5	-21.1	82.1	16.0	-27.4	56.2
	AC	11.4	-4.2	74.7	17.2	-12.7	81.2	15.7	-20.2	61.8
445	KL	-103.9	-41.2	62.9	-8.9	-8.2	75.0	21.8	-30.3	59.5
	AC	-81.8	-39.2	68.3	-6.3	-5.3	78.5	26.8	-32.2	62.8
362	KL	89.5	-0.5	-54.9	91.4	2.1	0.7	83.0	10.3	-11.5
	AC	100.0	4.1	-47.5	100.0	10.4	-29.7	85.6	15.6	-31.0

- Results presented in this table are the average values from three measurements

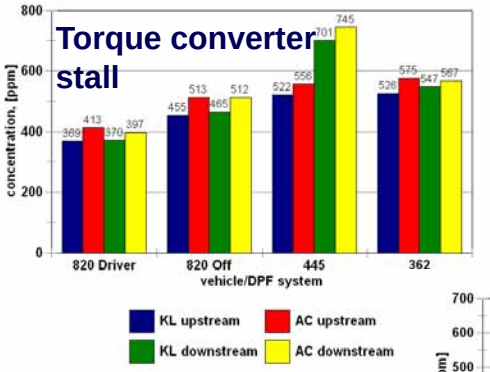
Gaseous emissions - Carbon Monoxide (CO)

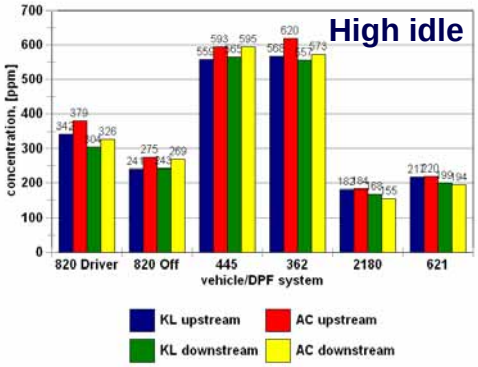




- Increase in CO emissions at TCS? Regeneration ?
- Reductions in CO emissions observed only for Engelhard filter installed on #362.
- Concentrations of CO in the exhaust of the tractors were much higher than those in the exhaust of the LHDs.

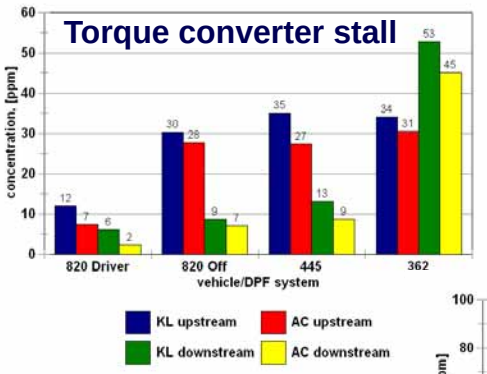
Gaseous emissions - Nitric oxides (NO_x)

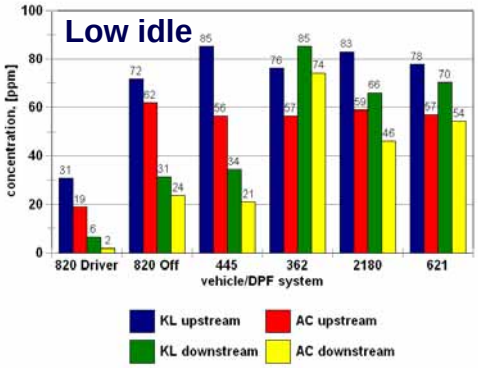




- NOx emissions were not not significantly affected by the filters

Gaseous emissions - Nitrogen dioxide (NO_2)





- The Engelhard filter increased NO_2 emissions from the #362 for app. 48 to 55% at TCS conditions.
- The concentrations of NO_2 downstream of the other filters generally were lower than those upstream of the filters.

Engine backpressure

Vehicle number	#820 driver	#820 off	#445	#362	#2180	#621
Backpressure, Torque converter stall, [in W.G./mbar]	23/58	33/84	80/203	72/183	N/A	N/A
Backpressure, High idle, [in W.G./mbar]	25/64	35/89	45/114	48/122	22/56	15/38
Backpressure, Low idle,[in W.G./mbar]	3/8	10/25	9/23	11/28	6/15	5/13

- The maximum back pressure allowed by DDEC is 42 in W.G. (107 mbar).

Conclusions

- Tested DPFs exhibited excellent efficiencies in curtailing DPM emissions.
- The efficiency of the DPF retrofitted to #445 was somewhat lower that the corresponding efficiencies of the other tested DPFs.
- Significant reductions in CO and significant increases in NO_2 emissions were observed for the passively regenerating DPF with platinum based catalyst coating (#362).
- The potential of an engine deration for curtailment of DPM emissions is evident from the results of emission measurements performed on #362 and #445.
- High engine backpressures were evident for some of the tested DPF systems.


Questions ???
10/29/2002
MDEC 2002, Markam, Ontario
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